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ANALYSIS OF THE EFFECT OF CONCORDE AIRCRAFT NOISE ON HISTORIC STRUCTURES

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Final Report

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16. Abstract

Statistical estimates of breakage probabilities from noise-induced vibration were calculated for susceptible structural elements at five historic sites near the proposed subsonic flight path of the Concorde aircraft. The five sites investigated were: Sully Plantation, Chantilly, ~~Virginia~~; Dranesville Tavern, Dranesville, ~~Virginia~~; Broad Run Bridge and Tollhouse, Loudoun County, Virginia; Manassas Battlefield Park, Manassas, ~~Virginia~~; and St. George's Church, Hempstead, New York. The structural features analyzed included windows, brick chimneys, stone bridge, and a plaster ceiling. The calculated breakage probabilities for these features were generally less than .001 for a year of projected Concorde overflights. ~~This is~~ considerably below the failure rate that would be expected just from exposure to the weather. The only exception to this was the probability of breakage of lites of glass at Sully Plantation which were already cracked and are expected to be replaced. The method of calculation used in this study was the response probability density function technique, which ~~has been~~ used in previous studies of structural response to aircraft noise, wa the method of calculation.

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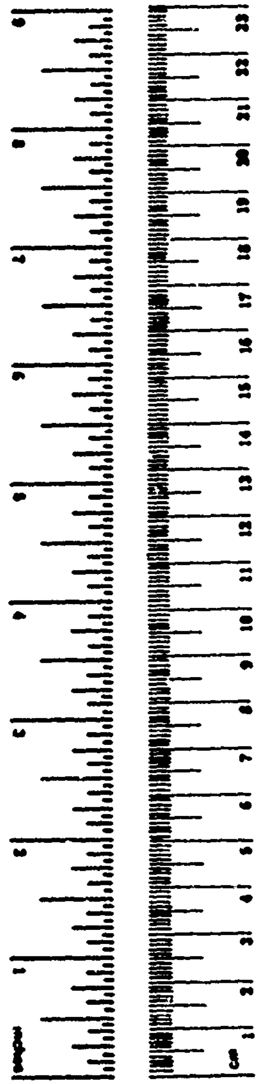
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

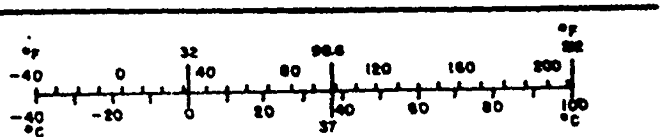
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

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I. INTRODUCTION

The Federal Aviation Administration (FAA) is analyzing various issues in connection with its environmental impact statement on proposed Concorde operations in the United States. One of these issues is whether the noise from subsonic Concorde overflights will damage the historic structures located near the flight paths. This study, prepared by Booz, Allen Applied Research, analyzes the structural damage question and presents estimates of various breakage probabilities, based on statistical modeling.

1. CONCORDE ENVIRONMENTAL IMPACT STATEMENT

On March 3, 1975, the FAA published the draft environmental impact statement on the Concorde Supersonic Transport Aircraft [1]. In the review of this draft, some points were raised which required further study. One area which was addressed was the question of whether or not the proposed subsonic Concorde overflights would cause vibration damage to various historic structures near the flight paths. It should be emphasized that such vibrations would be due solely to noise rather than sonic boom, since the Concorde will not be allowed to fly supersonically over land in the United States. The historic sites deemed worthy of investigation included St. George's Church in Hempstead, New York, near Kennedy Airport and four sites near Dulles Airport:

- Sully Plantation, Chantilly, Virginia
- Dranesville Tavern, Dranesville, Virginia

- Broad Run Bridge and Tollhouse, Loudoun County, Virginia
- Manassas Battlefield Park, Manassas, Virginia.

The above sites were chosen for investigation because they are listed in the National Register of Historic Places and they are located within a few miles of the proposed Concorde flight paths. This study analyzes the breakage probabilities of structural elements at these sites which might be considered to be susceptible to vibration, such as windows, mortar, and plaster.

2. VIBRATION TESTS OF CONCORDE OVERFLIGHTS

Two series of vibration measurements were conducted last year by the DOT Transportation Systems Center in connection with Concorde route-proving flights to the United States. These tests took place February 10-15, 1974, at Fairbanks International Airport, Fairbanks, Alaska [2, 3] and June 13-18, 1974, at Logan International Airport, Boston, Massachusetts [3]. The tests included measurements of noise levels as well as vibration levels of such structural elements as windows and walls from both the Concorde and the Boeing 707.

Analyses of the data from these tests by John E. Wesler of the DOT Office of Noise Abatement have shown that the vibration levels produced by subsonic Concorde overflights are significantly higher than those from the Boeing 707 [4]. This is due to the fact that the noise spectrum of the Concorde contains much more energy at low frequencies, as shown in Figure I-1. Structural members, such as windows and walls, generally have their resonant frequencies below 250 Hertz; thus, the low frequency noise from Concorde is much more

efficient in exciting them. This is shown in Figures I-2 and I-3 where window and wall vibrations from Concorde are at least 10 dB higher in most low frequency bands. Figure I-4 compares the wall vibrations from Concorde with those from other events. It can be observed from this bar chart that the subsonic noise from Concorde causes more severe wall vibrations than those from the Boeing 707 but not quite as severe as those from a 2 psf sonic boom. (Figures I-1 through I-4 are taken from Reference 4). In analyzing the data, Wesler found that average window vibration levels were 13.5 dB higher for the Concorde than for the Boeing 707, and average wall vibrations were 17.5 dB higher for the Concorde than the 707. Despite these vibration level differences the A-weighted sound levels for the two aircraft were equal, because the 707 spectrum has more noise near 2000 Hz, a band emphasized by A-weighting. Because of this fact, the equivalent pressure on a window is a factor of 4.73 (13.5 dB) higher for Concorde than for the 707, for a given sound level in dB(A). Similarly, the equivalent pressure on a window is a factor of 7.5 (17.5 dB) higher for the Concorde than for the 707. These factors will be utilized in the breakage probability calculations to be presented later in this report.

3. CONCORDE FLIGHT PATHS

The Concorde flight paths of Dulles and Kennedy Airports, which come closest to the historic sites, are shown in Figures I-5 and I-6. Note that the Concorde will come much closer to Sully Plantation than to any of the four other sites.

By using these flight paths and the takeoff and approach profiles for Concorde, the slant range for each site has been calculated. On the

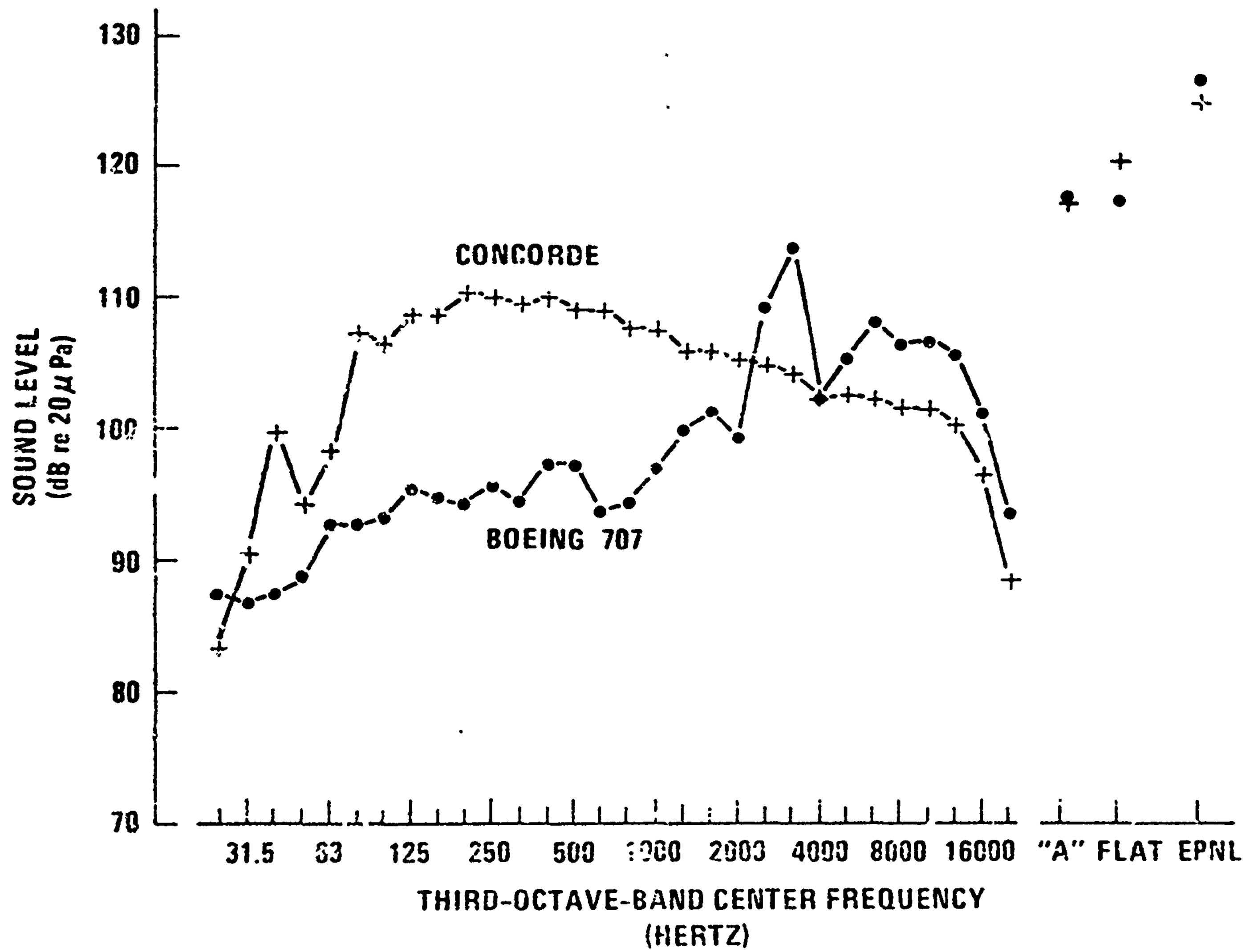
basis of these slant ranges, the maximum flyover sound level in dB(A) have been predicted at each site. These were calculated by using the transmission loss graphs shown in Figure I-7.

*　　*　　*　　*　　*

In Chapter II, the statistical technique for predicting the probability of damage to various structural elements will be described. Then, in succeeding chapters this approach will be applied in turn to each of the five historic sites.

FIGURE I-1

APPROACH NOISE LEVELS



WALL VIBRATION INDUCED BY AIRCRAFT DURING APPROACH

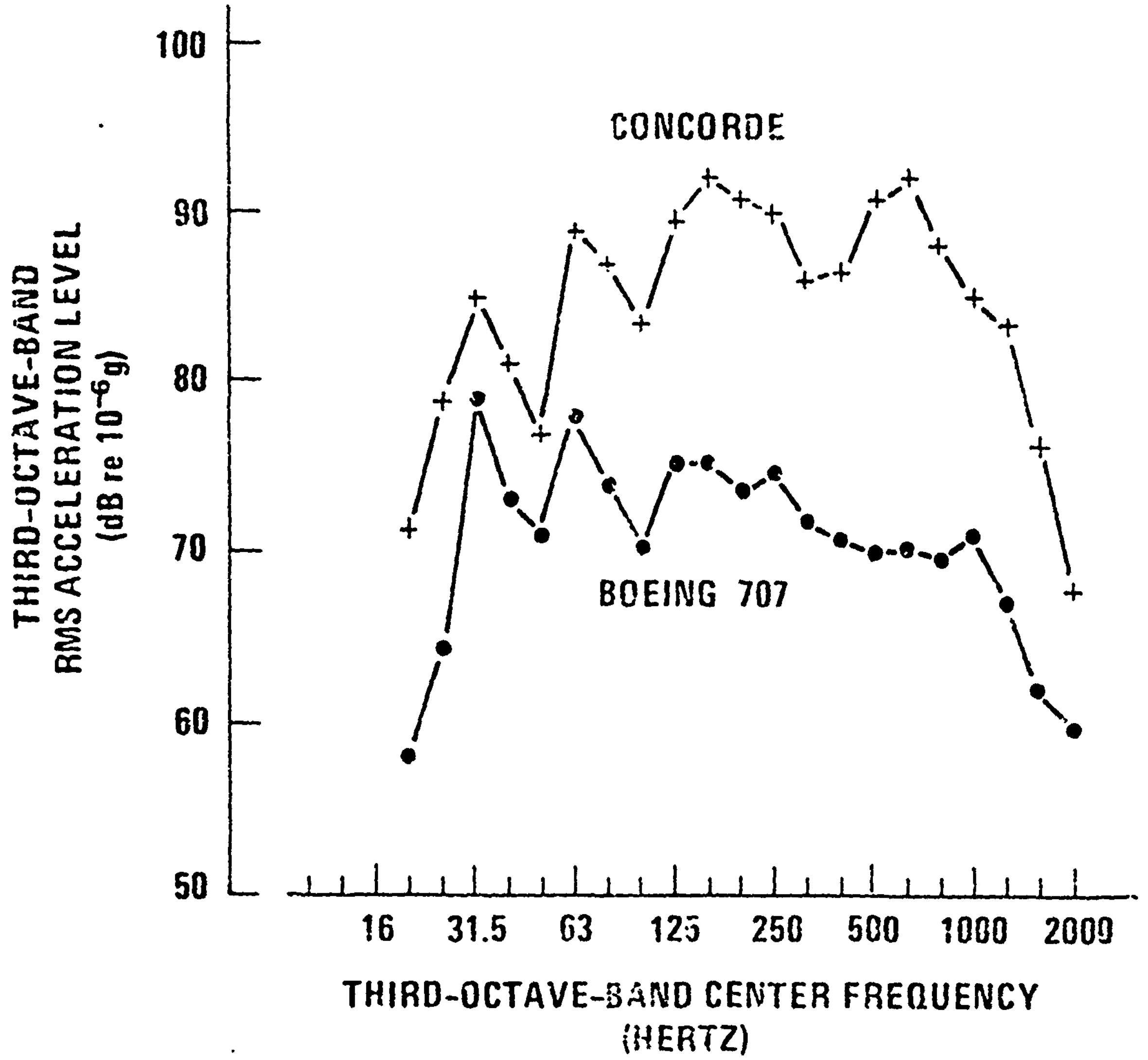


FIGURE I-3

WINDOW VIBRATION INDUCED BY AIRCRAFT DURING APPROACH

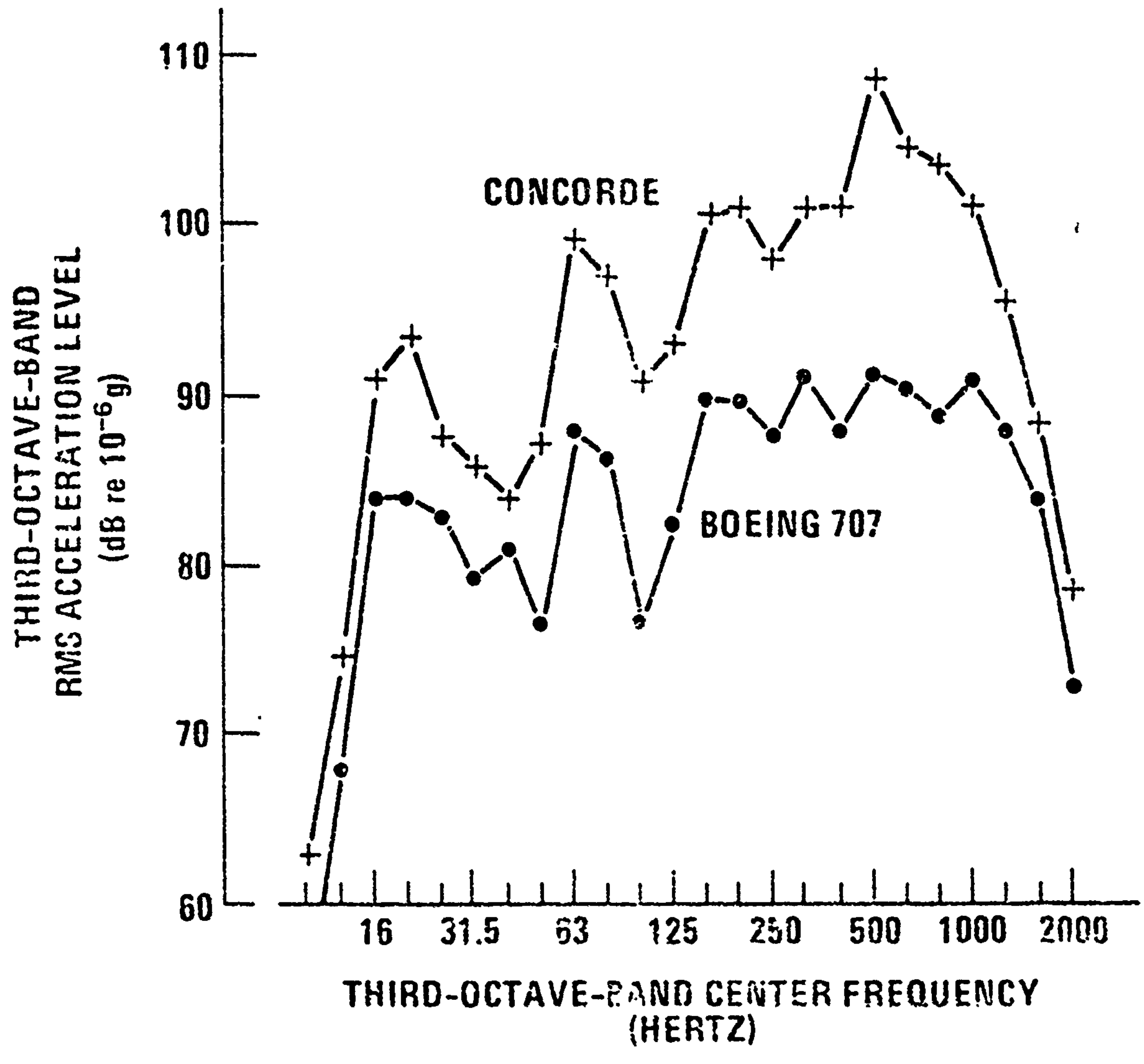


FIGURE I-4

WALL VIBRATIONS INDUCED BY TYPICAL EVENTS

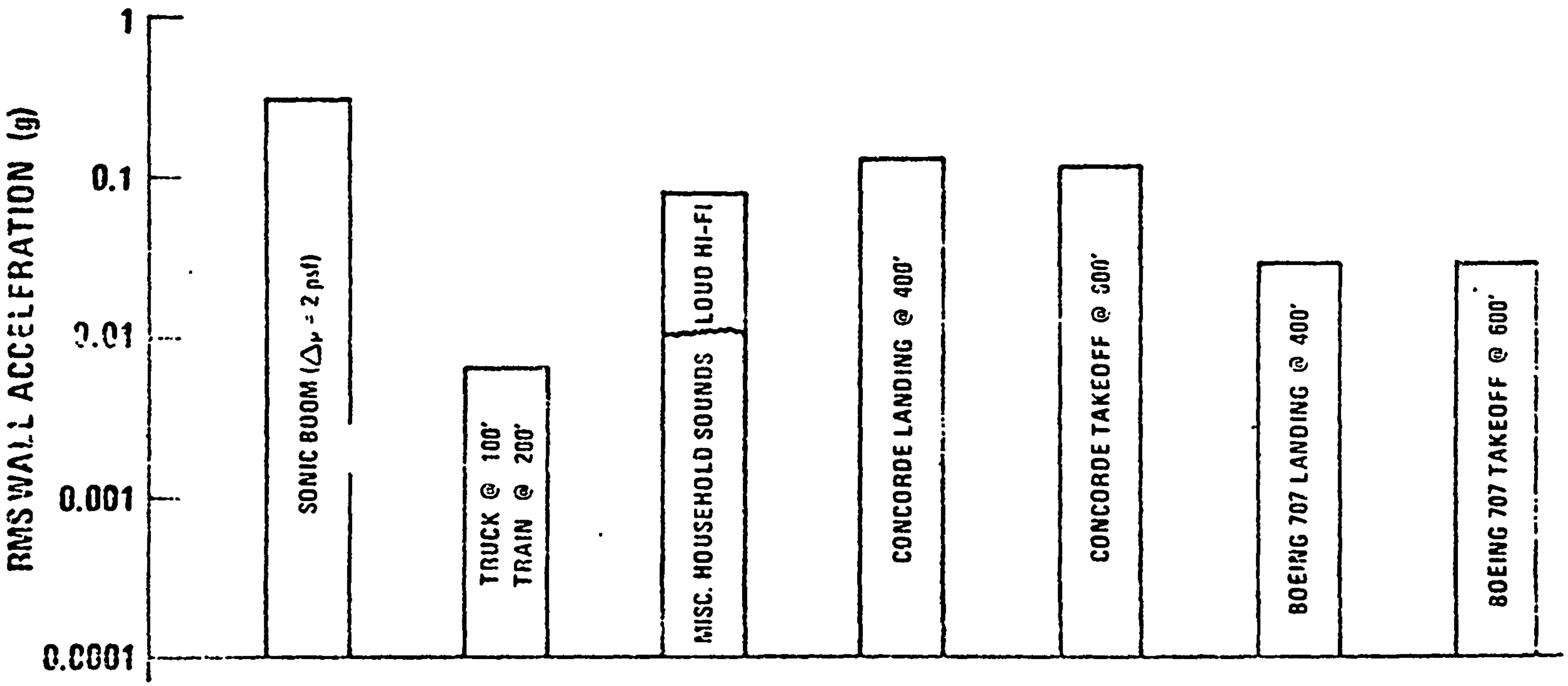


FIGURE 1-5
Dulles Airport Flight Paths

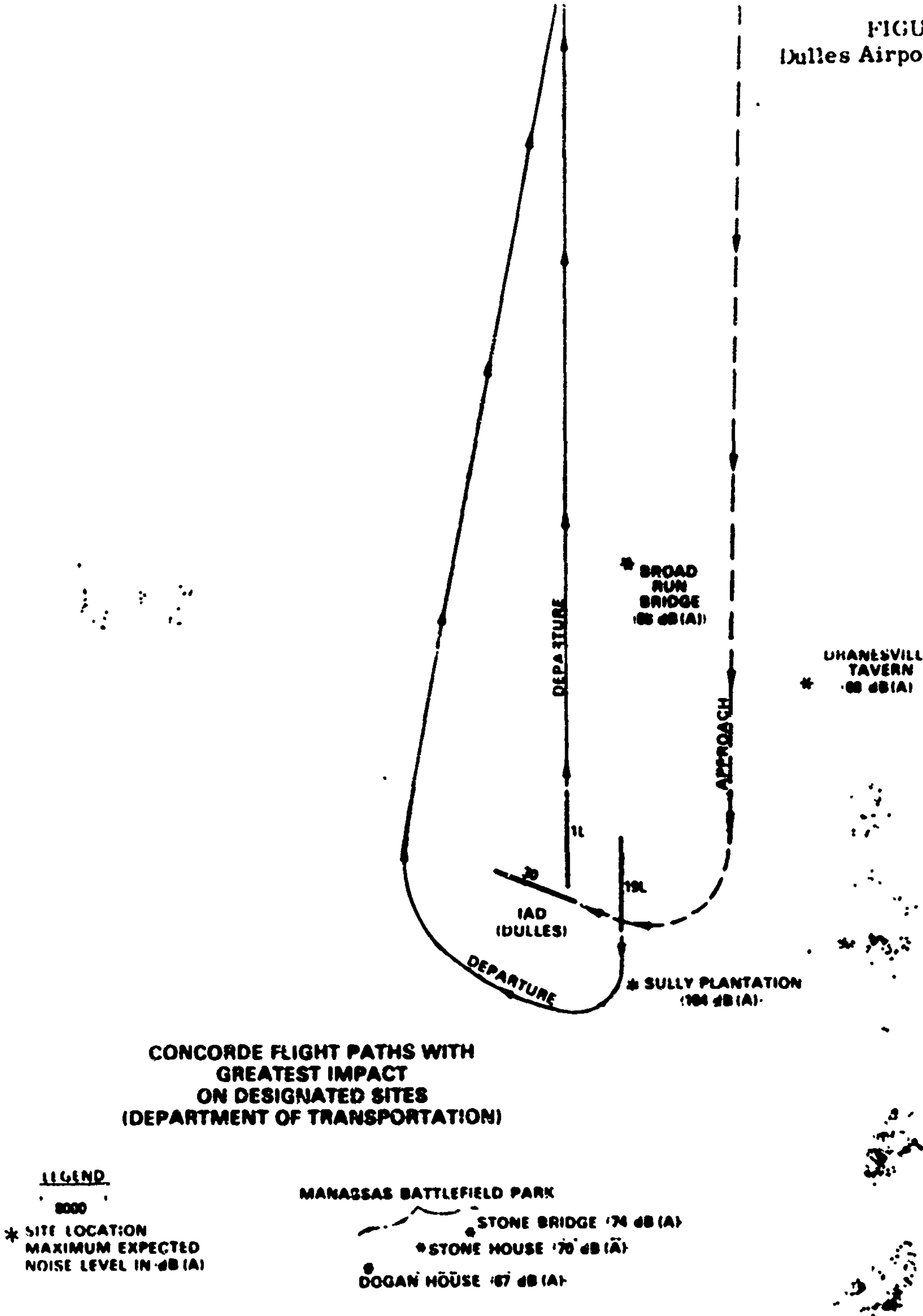


FIGURE I-6
Kennedy Airport Flight Paths

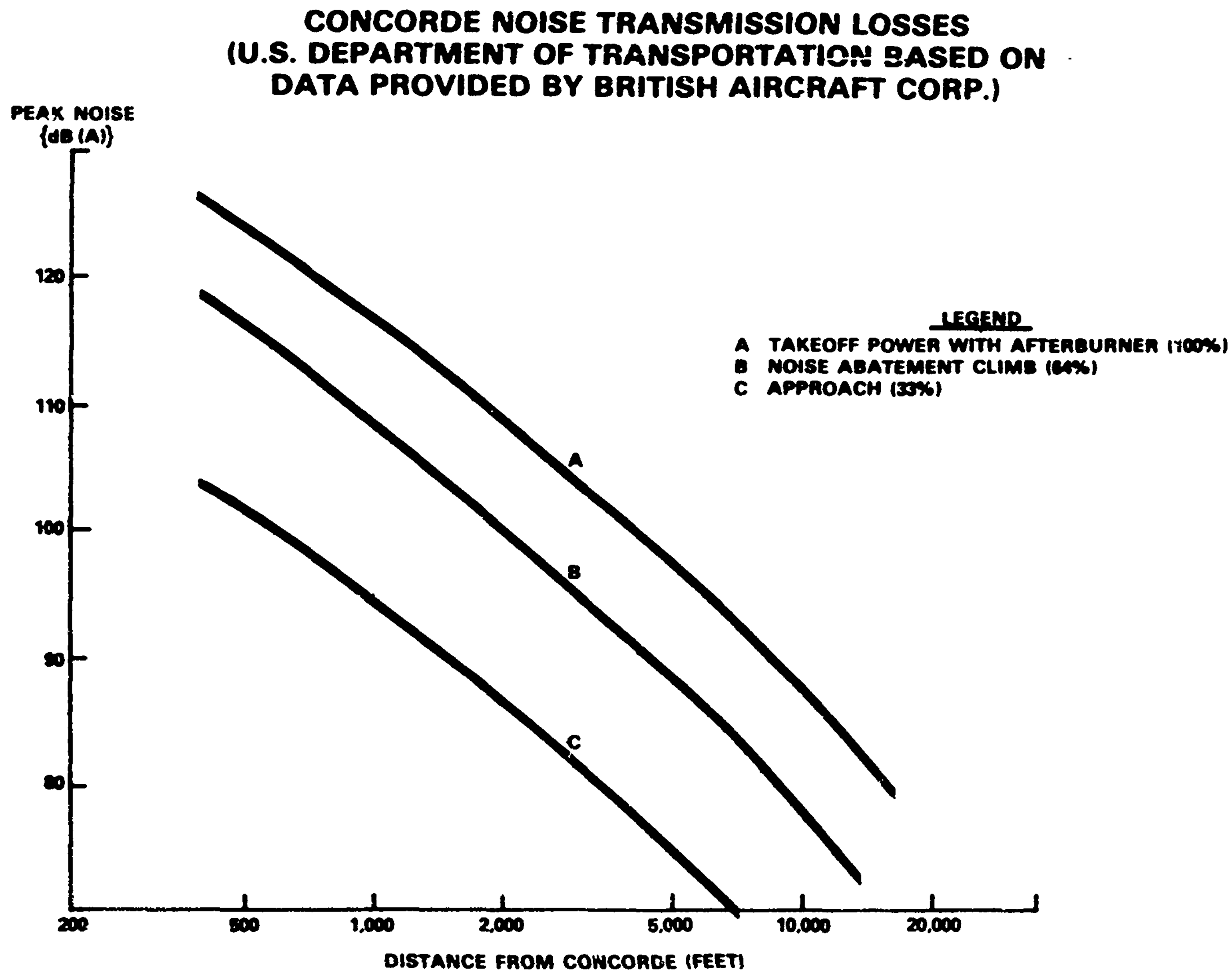


FIGURE I-7

Concorde Noise Transmission Losses

Table I-1
Maximum Noise Levels at the Historic Sites

Location	dB(A)
Dulles (IAD)	
Sully Plantation	104
Dranesville Tavern	68
Broad Run Bridge and Tollhouse	88
Manassas National Battlefield Park	
Stone House	70
Stone Bridge	74
Dogan House	67
Kennedy (JFK)	
St. George's Church	67

II. ANALYSIS

The structural materials which are most susceptible to vibration loading are brittle materials of relatively low tensile strength, namely window glass, mortar, and plaster. Each of these materials is likely to exhibit a wide variation among the strengths of individual specimens. The strength of glass is extremely dependent on surface scratch condition, while the strength of plaster and mortar depends on workmanship and individual batch composition. Similarly, the stress from aircraft noise loading exhibits a wide variation. Because the stress and strength are so variable, they must be treated as statistical distributions rather than as deterministic numbers. This chapter discusses the technique for treating the vibration damage problem statistically and predicting the probability of breakage.

1. RESPONSE PROBABILITY DENSITY FUNCTION TECHNIQUE

The response probability density function technique is the method which has been used in earlier studies to find the probability of glass breakage from sonic boom and jet noise [5, 6, 7, 8, 9]. In this technique the maximum stress from the aircraft noise and the strength of the material are both modeled with lognormal probability density functions (pdf's) to agree with the forms of probability density functions found in previous experimental studies. Because of the nature of lognormal pdf's, the probability of breakage can be easily calculated.

The maximum stress can be expressed by an equation which we have developed from experimental data in our previous studies,

$$\sigma_m = p_n\ R_n\ F, \tag{1}$$

where σ_m is the maximum stress in the material, p_n is an effective pressure derived from a noise level reading, R_n is a noise stress factor (like a dynamic amplification factor), and F is the stress factor, which depends on the material configuration.

As in previous work by the authors, the strength of the window is modeled by the equation

$$\sigma_b = p_b\ F, \tag{2}$$

where σ_b is the breaking strength of the material, p_b is the breaking pressure of the material, and F is the stress factor.

Then the effective factor of safety N_e is

$$\begin{aligned} N_e &= \sigma_b/\sigma_m \\ &= p_b\ F/p_n\ R_n\ F \\ &= p_b/p_n\ R_n. \end{aligned} \tag{3}$$

Taking the common logarithm of Equation (3), we obtain

$$\log N_e = \log p_b - \log p_n - \log R_n. \tag{4}$$

Since both R_n and p_b are lognormal, it follows that $\log R_n$ and $\log p_b$ are gaussian. Since for any given noise level p_n is deterministic, then $\log N_e$ is gaussian. Then the expected value (mean) of $\log N_e$ and its variance are found by the following equations.

$$E(\log N_e) = E(\log p_b) - \log p_n - E(\log R_n) \tag{5}$$

$$Var(\log N_e) = Var(\log p_b) + Var(\log R_n) . \tag{6}$$

Using the values of $E(\log N_e)$ and $Var(\log N_e)$ from the above equations,

$$z = \frac{E(\log N_e)}{\sqrt{Var(\log N_e)}} \tag{7}$$

Since z is a zero mean unit variance normal random variable, the value of the probability of breakage is simply found by looking it up opposite z in a standard table of the normal probability density function. This is because of the nature of the pdf of $\log N_e$ as shown in Figure II-1. The area to the left of $\log N_e = 0$ represents the probability that the strength is less than the stress and the material fails. This area thus corresponds to the probability opposite z in the gaussian table.

Using the approach described above requires experimental data on the response of structures to aircraft noise, in order that R_n may be determined. These data were obtained from analysis of experimental subsonic overflights which were part of the sonic boom tests conducted at Edwards Air Force Base in 1966 [10]. In these tests, four windows were instrumented with strain gauges and a KC-135 aircraft was flown over them. For each overflight, the strain on each of the windows and the outdoor sound level in dB(A) was recorded. There were 50 such overflights, providing data for calculating R_n for four sizes of windows. The KC-135 has a spectrum very similar to the Boeing 707. As was mentioned in the previous chapter, there are experimental data from the Anchorage tests which compare the vibration response of structures

to Concorde noise with that from 707 noise. Thus, with the Edwards Air Force Base data, we have the means of finding the response of a structure to a Concorde sound level in dB(A).

The effective rms pressure in pounds per square foot p_n is defined here by the equation

$$p_n = \exp(.1151\, L - 14.6885), \tag{8}$$

where L is the sound pressure level in dB(A) and the two numerical values account for conversion factors for converting dB(A) to dynes/cm^2 and dynes/cm^2 to pounds per square foot (psf).

R_n was calculated for each overflight of each window from the equation

$$R_n = \sigma_m / p_n\, F, \tag{9}$$

where σ_m is obtained from the strain gauge reading, and F is calculated from the window dimensions.

In adjusting from the Edwards Air Force Base data to Concorde overflights, it is necessary to multiply the effective pressures by the factors from the Anchorage experiments, which were mentioned in the previous chapter. Thus,

$$p_n\ (\text{Concorde}) = 4.73\ p_n\ (\text{KC-135})\ \text{for windows} \tag{10}$$

$$p_n\ (\text{Concorde}) = 7.5\ p_n\ (\text{KC-135})\ \text{for walls.} \tag{11}$$

Using Equations (5), (6), (7), and (8) with the appropriate statistical values for the materials, the probability of breakage was found for each susceptible element of the historical structures.

2. STRUCTURAL ELEMENTS

The structural elements whose breakage probabilitie: ~ere calculated were windows, chimneys, bridges, and plaster. The ...cure of these materials is described in the following subsections.

(1) Windows

One difference between glass and metals is the "static fatigue" property of glass. Glass acts weaker for longer duration loads. Thus, in comparing laboratory static tests on glass with a 60-second duration to Concorde overflights with a 6-second duration there is a large increase in apparent strength. Glass acts 40 percent stronger toward the short duration overflight [11]. Most windows are designed for static loading considerations, which are usually more severe because the wind spectrum usually has most energy at very low frequencies. Also by the "static fatigue" properties of glass, the material exhibits more strength for loads that are rapidly applied and removed than for long-term static loads.

Another distinguishing characteristic of glass is that its strength is a surface condition property rather than a material property. Thus, its strength can vary from 2 kpsi to 250 kpsi, depending on whether the surface is sandblasted or in pristine condition. Even lites of glass which appear identical will have different patterns of depth and locations of tiny surface flaws and hence different strengths. Because of this heavy dependence on surface condition, the lites of glass from a single lot will exhibit a wide range of strength values, depending on the handling

each individual lite of glass has received. However, the mean and standard deviation of the strength will remain the same from lot to lot, providing the glass is the same type and size. In the data we have analyzed the pdf for the glass strength is generally lognormal.

In addition to the considerations described above, one must also consider the condition of the glass. Data describing the strength of old weathered glass as opposed to new glass are extremely sparse. The existing data [12] indicate that the strength of used glass is approximately half that of new glass. All that has been said thus far applies only to healthy glass. A rule of thumb in the glass industry for the strength of cracked glass is that it is that it is 1/10 that of healthy used glass.

(2) Chimneys

Some of the historic structures considered in this study include brick chimneys. The possible failure mechanism for such chimneys is through lateral loading causing a tension failure of the mortar. Thus the governing material property is the tension strength of the mortar.

We obtained experimental data on the tensile strength of mortar [13, 14] and determined that its pdf appears to be lognormal. Using the material statistics we were able to determine the breaking pressures of the chimneys at the historic sites by assuming beam loading.

(3) Bridges

The two stone bridges considered in this study both had arch-type construction. In this type of construction the weight of the stones contributes to the strength of the bridge by providing a compressive stress which any tension stress must overcome. Our thorough analyses of the bridges has shown no mechanism by which this could occur for vibration from Concorde noise, and hence there is zero probability of breakage from this cause. The bridges would be much more susceptible to loading from floods, such as washed out part of Broad Run Bridge during hurricane Agnes.

(4) Plaster

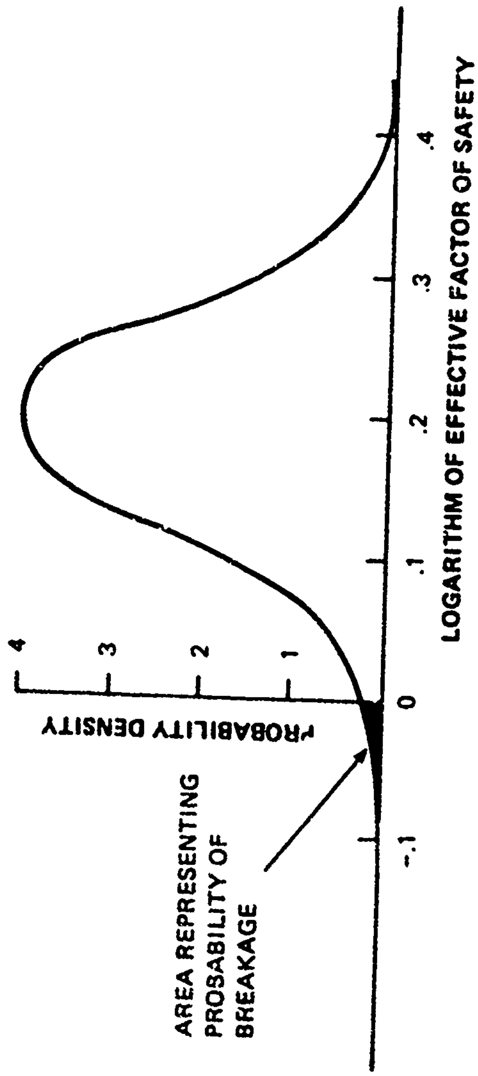
Plaster is manufactured by heating (calcining) gypsum at 300-350°F. The calcining process drives off water vapor and changes the state of the material from dihydrate calcium sulfate to hemi-hydrate. The calcined gypsum can be used to form various plasters at the building site, depending on the aggregate with which it is mixed. In the type of construction which was used when Sully Plantation was built the aggregate consisted of lime and sand. When the plaster and aggregate are mixed with water they form a slurry and entrapped air bubbles float out. The proportioning of ingredients, the thoroughness of mixing, and the removal of air bubbles all depend on the workmanship of the individual plasterers. For this reason plaster shows considerable variation in strength. As the plaster sets a crystalization process takes place and the gypsum returns to its dihydrate form and bonds in the aggregate materials.

Generally the plaster is applied to a wall or ceiling in three coats. The first two coats in old structures such as Sully Plantation contained horsehair as a binder material. The first coat, called the "scratch coat" was applied directly onto a rough-hewn wood lathing. Its surface was then scratched with a rough tool to provide better adherence to the following coat. The next coat, called the "brown coat," was somewhat thicker and also contained horsehair. The finish coat, which contained no horsehair, was then applied over the brown coat. The total thickness for three coats was about 1/2 inch thick. In evaluating the strength of plaster for this study, the data from previous investigations were used [15, 16].

* * * * *

This chapter has discussed the analysis of the probability of breakage for various materials. In the succeeding chapters the methods cited are applied to estimate breakage possibilities for each historic structure from Concorde noise. In each succeeding chapter the history of the structure is summarized and the structure itself is described. The breakage probabilities calculated for various structural elements are then presented.

FIGURE II-1
Probability Density Function of the Logarithm
of the Effective Factor of Safety



III. SULLY PLANTATION

1. HISTORY AND DESCRIPTION OF STRUCTURE

Sully Plantation is located in Chantilly, Virginia, on Route 28, 3/4 mile north of U.S. Route 50 and 4 miles south of the Dulles Access Road. Richard Bland Lee built Sully in 1794 shortly after he was married to Elizabeth Collins, daughter of a prominent and wealthy Philadelphia Quaker Merchant. Sully was completed in 1795. The two-and-a-half story, three-bay house resembles the architectural styles of houses of that period in Philadelphia. Its plan is asymmetrical with the side hall giving access to a nearly square dining room and parlor on the first floor. Upstairs are two spacious bedrooms, and on the garret story are a large chamber and a small lodging room. A full length piazza with scrolled boards at the roof line spans the south side of the house. A covered walkway connects the dining room to the nearby yard kitchen-laundry. The interior of the walkway is finished in stucco.

Flush beaded siding covers the heavy timber framing and brick nogging insulation. The interior walls and ceilings are plastered. Some original plaster still remains on the ceiling of the garret story, although it has been patched several times during the 108-year history.

The original plaster was applied in three coats: a scratch coat, a brown coat, and a finish coat. Figure III-1 shows original lathes. The first two layers are composed of identical material but applied in a

different fashion. The scratch layer is very thin (about 1/8 inch) and is applied directly to the wooden lathes. The surface is roughened so that the brown coat will create a good bond. The brown coat is then applied and the surface left smooth. The thickness of the brown coat varies since this coat is used for leveling the walls. A finish coat is then applied very lightly providing a smooth finish. This coat is composed of slaked lime and gypsum. The plaster in the garret room is essentially original except in areas where it was patched. (See Figure III-2.)

There are two massive twin chimneys and brick pent wall on the west side of the house as shown in Figure III-3. Today the chimneys have been partially reconstructed at two different times due to damage from lightning. The mortar was basically composed of lime mortar, crushed oyster shells and sand used from the surrounding area. The foundation is original and made of Virginia red sandstone. The mortar used in the foundation is identical to that used in the chimneys. Originally the partial basement had a tamped dirt floor.

In 1799 a one- and-one half story wing was added to the east side. This was left during the restoration, although subsequent additions were removed to return the house to its early 19th century condition.

Under Lee's management, Sully prospered with harvests of tobacco, corn, wheat, rye, timothy, clover, apples, and peaches. In 1802, Lee added a large stone dairy which still stands today. Due to financial difficulties, Richard Bland Lee was forced to sell Sully in 1811 to his second cousin, Francis Lightfoot Lee.

Jacob Haight, a Quaker farmer from New York, bought Sully in 1842. He developed Sully into a model farm. Haight attached a convenient lean-to kitchen on the west side of the house which has since been removed during current restoration.

Haight's children, Alexander Haight and Maria Haight Barlow, maintained Sully through the Civil War. On September 1, 1862, the Union and Confederate armies clashed in the "Battle of Chantilly" a few miles east of Sully. During the Civil War, Sully was visited by the Confederate Generals Pierre de Beauregard, J. E. B. Stuart, Wade Hampton, Fitzhugh Lee, and Colonel John Mosby, the "Gray Ghost" and his famed Rangers.

In 1870, the Barlows sold Sully to New Yorkers Stephen and Conrad Shear who farmed it until 1911. During the early years of the 20th century, Sully was operated as a dairy farm. Sully became the private home of two diplomats until 1958 when construction of Dulles Airport threatened to destroy it. Because of Sully's historical and architectural significance, Sully has been placed on the National Register of Historic Places.

Sully is presently being restored to its early nineteenth century appearance by the Fairfax County Park Authority and will shortly be opened to the public.

2. PROBABILITY OF BREAKAGE

The structural elements at Sully whose breakage probability was evaluated included windows, chimneys, and original plaster.

Figure III-2 shows a typical Sully window, the one in the garret room. Note that it is a "twelve-over-twelve" consisting of twenty-four 8- by 10- by 1/16-inch lites. Some of the other windows at Sully have different configurations with fewer of the same size lites but the twelve-over-twelve is most typical. Among all the windows at Sully there are 324 lites. Approximately half are original; the rest have been replaced with "reproduction glass." This replacement glass (costing $1.45 per lite) is made in the old way, by pouring molten glass onto a flat surface rather than rolling it. This process results in an uneven surface where the thickness varies between 1/16 inch and 1/8 inch. In the process of restoring the structure all the old lites which could be saved were removed and then re-installed in fresh putty without glazier points. This emission of glazier points was done to eliminate stress concentrations when the glass is subjected to aircraft noise. All the lites at Sully had a transparent plastic Scotchtint film cemented to their surface to aid in reflecting sunlight. This thin film does not add appreciably to the strength of the lite but it will hold the pieces in place if a light becomes cracked.

Observation of the lites at Sully disclosed that at least four of them were cracked. These lites have only 1/10 the strength of healthy lites, since it takes much less pressure to run an existing crack than to start a new one.

Present overflights near Sully already cause some vibration of the windows. During our visit to Sully we noted that the lites in the garret room window vibrated sufficiently to be easily detectable

by a fingertip touch each time an overflight occurred. We made several outdoor sound level meter measurements at the site. The largest reading we observed for an overflight was 94 dB(A). Some personnel of the Fairfax County Park Authority assigned to Sully believe that the present overflights are causing window cracking. It is reported that one observed a freshly cracked lite after a particularly loud overflight.

As indicated in Table I-1 our calculations are based on a sound level of 104 dB(A) for each Concorde overflight passing Sully. This translates to an effective pressure of .313 psf. The breaking pressure of the healthy lites is 492 psf under a static load of 6 seconds duration, the length of time for the noisiest part of a Concorde overflight. Using the method described in Chapter II, which accounts for dynamic loading and for the variance of the strength and the stress estimates a probability of breakage of 1.7×10^{-12} for a healthy lite from a single overflight. Considering that there are 324 lites and 1460 Concorde overflights are expected past the site each year the probability of breakage of one healthy lite of the 324 within a one year period is $(1.7 \times 10^{-12})(324)(1460) = 8 \times 10^{-7}$. This probability is equivalent to about one healthy lite every million years.

The probability of breaking lites which are already cracked is considerably greater since they have only 1/10 the strength of healthy lites. The probability of a cracked lite failing during an overflight is .0013. This corresponds to a probability of breakage of .19 for a year of overflights. For the four lites observed cracked

the probability is thus 80 percent that one of them will break during a year of overflights. Since already cracked lites have a risk of breaking, it would be appropriate to replace them with healthy lites. Apparently this already is the policy at Sully since about half of the lites have already been replaced.

(2) Chimneys

In analyzing the breakage probabilities of the chimneys they were modeled as cantilever beams with additional support from the brace as shown in Figure III-3. The type of failure which was considered was the first cracking of the mortar from an overturning force from lateral vibration. The approach of Chapter II yielded an estimate of the probability of failure of 7.9×10^{-10} for each Concorde overflight on each chimney. Considering the proposed Concorde schedule and the fact that there are two such chimneys, the failure of a chimney from Concorde noise has a probability of occurrence of 2.3×10^{-6} per year. This is equivalent to an estimate of 440,000 years between failures.

(3) Garret Room Plaster

The garret room ceiling is plastered with a lime and sand plaster, some of which is believed to be the original plaster used in the Sully Planatation. The plaster is supported by pine laths strung across 2- by 8-inch joists at 2-foot centers which are members of the roof trusses. Each joist is approximately 15.5 feet long.

The plaster may fail if the tensile stress exceeds 100 psi at any point (14). Tensile stresses may be induced if the ceiling, including the joists, laths and plaster is deflected by a uniform load, such as that from the noise of Concorde overflights. The maximum tensile stress will occur on the surface of the plaster that is exposed in the garret room. For the purpose of this analysis breakage is deemed to occur if the plaster surface cracks.

The outdoor noise level at Sully Plantation from Concorde operation is 104 dB(A). Using an attenuation factor of 20 dB through the wood shingle insulated roof, the sound level at the plaster would be 84 dB(A), or .0066 psf. Because of sensitivity of plaster to low-frequency noise present in the Concorde spectrum, an amplification factor of 7.5 should be allowed so that a maximum overpressure of .05 psf would result on the plaster surface.

Following the calculation procedure of Section II, and a mean breaking stress of 100 psi for plaster, the probability of failure will be 1.71×10^{-7} per flight. With four flights daily, 365 days a year, the probability of failure is 2.5×10^{-4} or once in 4000 years.

FIGURE III-1
Original Laths at Sully Plantation

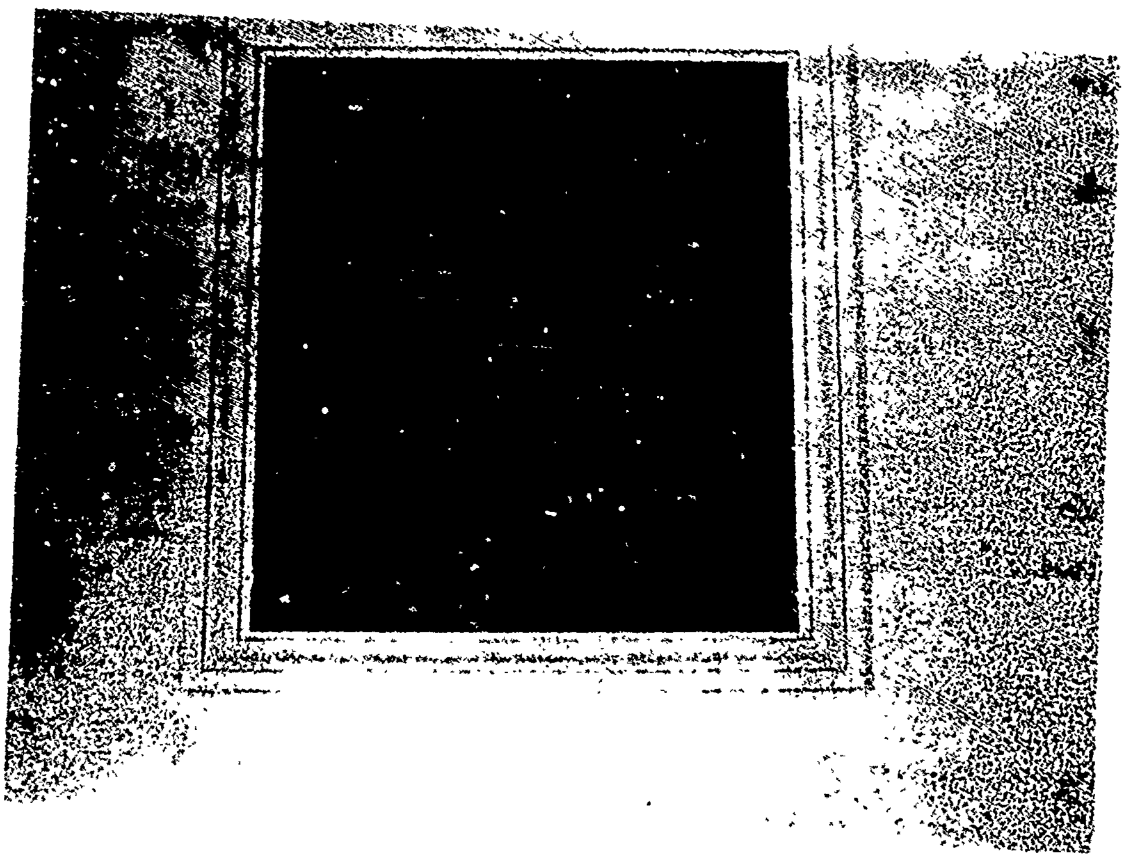


FIGURE III-2
Original Plaster in Garret Room
of Sully Plantation

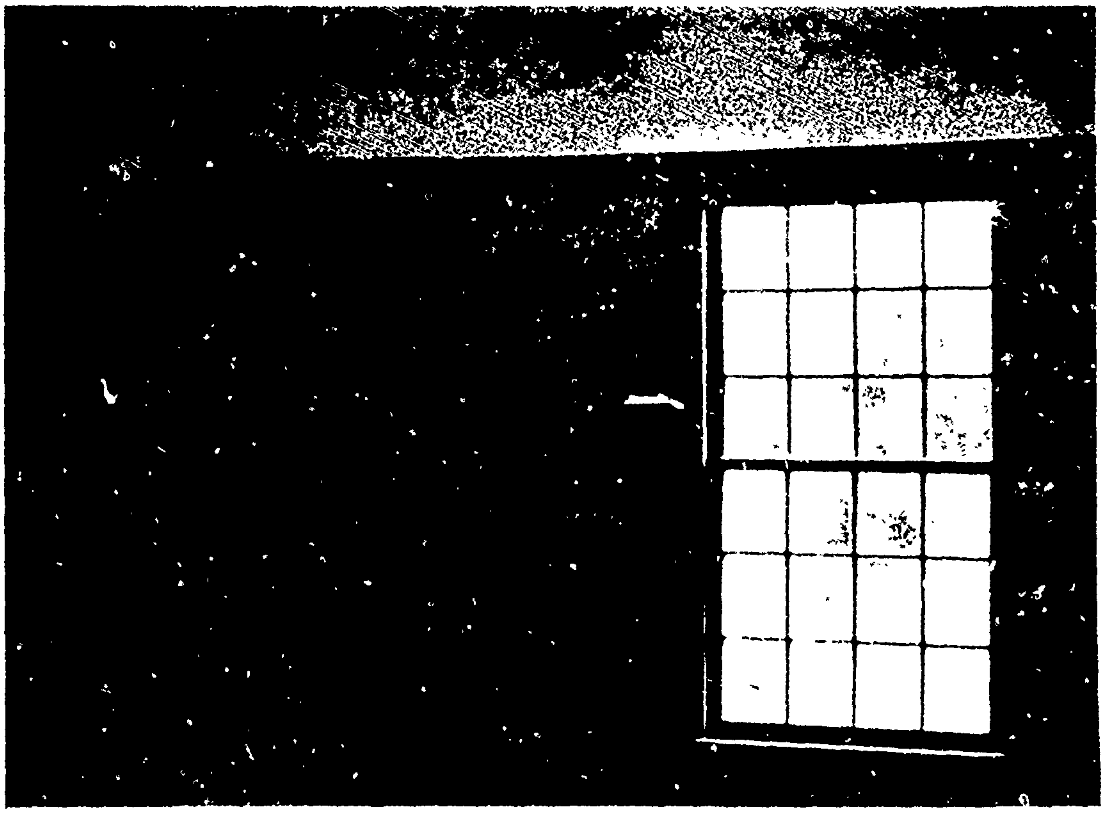


FIGURE III-3
Chimneys and Pent Wall
at Sully Plantation

IV. DRANESVILLE TAVERN

1. HISTORY AND DESCRIPTION OF STRUCTURE

The Dranesville Tavern is a two-story wooden structure located about 1 mile west of the junction of Route 193, the Georgetown Pike, and Route 7, the Leesburg Pike in Fairfax County, Virginia. The Tavern is typical of an ordinary early 19th century tavern used to serve the common man. The Tavern played an important part in the Turnpike Era and later as a drovers' rest for wagoners using these pikes.

The Tavern was believed to have been built as early as 1820. When originally constructed, it comprised two basic log buildings: one a kitchen, and the other a two-story enclosed dog run type structure. These two buildings were joined by a story and a half modified post and beam section with an enclosed porch across the south side of this connecting section and the kitchen. Under the porch was a small root cellar.

About 1850 the structure assumed basically the same appearance it has today—a full two-story structure, sheathed with weatherboarding, as shown in Figure IV-1. Some changes in the front and rear porches occurred near the end of the 19th century, but these changes were cosmetic and did not basically alter the mid-century fabric of the structure.

A drovers' rest or wagon stand, the Tavern was the commonest type of inn or tavern, specializing in serving the working traveler rather than the stage coach trade. Its inception followed closely the establishment of the Leesburg and Georgetown Turnpikes, and it was completed soon after these two met at the junction which became Dranesville.

The Tavern is of great importance not only as an example of a 19th-century Turnpike tavern, but also because of the long period of time it served a use compatible with the use for which it was constructed. Its last owners, the Jenkins family, operated it as a hostelry serving the traveling public from 1881 to 1946, some 65 years. The last paying guest did not leave the tavern until 1963, some 87 years after the family began operating the facility, and only a few days before it was acquired by the Fairfax County Park Authority.

At that time, 1968, the structure survived almost completely from the c. 1850 period, a vernacular Greek Revival structure, of a type which is fast disappearing. With remarkably few exceptions, the complete structure stands, including chimneys, doors, floors, door and window hardware, weatherboarding, finish, and even a majority of the early glass.

In May 1968, the Tavern was acquired by the Fairfax County Park Authority and was moved from its original site, which was in the path of highway construction. On the new site it was oriented in the same relationship to the compass as on the old site. The building is currently in a state of total disrepair. See Figure IV-2. Fairfax County Park Authority plans to momentarily commence complete restoration of the building to its appearance as a 19th century tavern. Restoration will take approximately 1 year. At that time the Tavern will be opened as an operating tavern to the public.

2. PROBABILITY OF BREAKAGE

(1) Windows

Maximum sound level due to Concorde overflight at Dranesville Tavern is estimated to be 68 dB(A), resulting in a pressure

of .005 psf over the windows. The sound levels due to heavy traffic on Routes 7 and 193 were observed to be higher than the levels due to overflights of current subsonic jet aircraft.

The Tavern is currently in a state of disrepair and several lites are cracked. Most glass is considered to be original, though most or all of it may be replaced during the planned reconstruction. The average lite size is 10 by 12 inches, with a thickness of 1/16 inch. The strength distribution and stress factors will be similar to those at Sully Plantation.

Using the procedure outlined in Chapter II, the probability of failure of a cracked lite is obtained as 5×10^{-22} per overflight. Assuming that all 210 lites are cracked, this would mean one failure per 6.55×10^{15} years due to the noise from Concorde overflights.

(2) Chimney

The Tavern has four chimneys of stone and mortar construction. All the chimneys are in a very unsound condition and the chimneys on the west side are held together temporarily by wooden scaffolding (Figure IV-2). The eastern chimney appears today as it did in the earliest period. The west chimneys were completed c. 1850, and the taller kitchen chimney appears to be made of two distinct sections, with the stonework above the present roof level not as well and carefully constructed as the work below. This chimney is the one most likely to suffer damage from Concorde overflights. It has an unsupported height of 20.67 feet above the shoulder at the first story level.

Sound levels due to Concorde overflights are estimated to reach 68 dB(A) at the Dranesville Tavern. This would result in an effective overpressure of .008 psf over the chimney surface including the allowance for Concorde low frequency noise.

One of the mechanisms of failure of the chimney would be caused by excessive tension in those portions of the mortar that are not under any compressive loads due to the unevenness of the stone layers.

The maximum tensile stresses will occur due to lateral bending of the chimney from overpressure acting on one of the chimney faces. Taking into account the 4-foot width of the chimney and its cross-sectional moment of inertia, the maximum stress due to bending will be 209 times the overpressure.

The mean value of breaking strength of mortar under tension is 6134 psf. Equating this to the maximum bending stress, the overpressure required for failure is obtained as 29.3 psf.

Using the method outlined in Chapter II for chimneys, the probability of failure of the kitchen chimney is 1.2×10^{-15} per Concorde overflight, or once in $5.8. \times 10^{11}$ years. The probabilities for failure of the other three chimneys will be lower because of the lower induced stresses in them.

FIGURE IV-1
Dranesville Tavern

FIGURE IV-2
Unrestored Chimneys at
Dranesville Tavern

V. BROAD RUN BRIDGE AND TOLLHOUSE

1. HISTORY AND DESCRIPTION OF STRUCTURE

Broad Run Bridge and Tollhouse is located at the intersection of Routes 2 and 78 and is one of a series of toll bridges built to service the Leesburg Turnpike.

On February 3, 1809, the Virginia General Assembly passed an act incorporating the Leesburg Authority for purposes of building a road from Leesburg to the Little River Turnpike at Alexandria. The road was to be 50 feet wide. In February 1816, an act creating a "Fund for Internal Improvement" was established to consist of shares held by the Commonwealth, in various turnpikes, canals, and banks, and of dividends received from such stock. Thus, the need for better inland communication to promote commerce and travel to the west was recognized by the government.

The work on the Leesburg Pike progressed slowly, but by 1822 the road had been completed to Dranesville, a distance of 14 miles.

Sometime after 1820, the stone bridge of Broad Run was built. The bridge has a double span of arches supported by a central pier and massive abutments on either bank. At the beginning of the Civil War, the turnpike ceased to be a toll road. The stone bridge was in use until 1949, when it was replaced by a concrete and steel bridge. The toll-house connected with the bridge is also stone, one-story, and was later

enlarged by the addition of three wings. Originally, an attendant lived in the tollhouse. The old walls of the tollhouse are relatively intact but little original interior fabric remains. See Figure V-1.

The bridge is reported to have been built by Croziet, the post revolutionary bridge builder. Broad Run Bridge and Tollhouse represents the only example left on the turnpike where both the bridge and the tollhouse are still in existence.

In 1970, the bridge was half washed out by Hurricane Agnes and has not been rebuilt. See Figure V-2. The Commonwealth of Virginia— Department of Highways owns a portion of the bridge. The tollhouse is privately owned. The tollhouse served as a private residence until Hurricane Agnes damaged it. There has been some repair work done on the tollhouse since the hurricane, but it still stands vacant.

Broad Run Bridge and Tollhouse is listed as a state historic site in the National Register of Historic Places due to its significance in the development of Commerce. The bridge is accessible to the public although the Stone House is not.

2. PROBABILITY OF BREAKAGE

(1) Bridge

As mentioned earlier, the bridge was half washed out by Hurricane Agnes in 1970 and has not been rebuilt. Hence, there is concern with the probability of further damage to the remaining single span.

The sound level at Broad Run Bridge due to Concorde operations is estimated to be 88 dB(A). This would result in an overpressure of .08 psf, taking into account the low-frequency characteristics of the noise.

The failure mechanism of a stone bridge of this type is extremely complex. During Hurricane Agnes, it is believed that the record high flood level of Broad Run, which completely submerged the bridge for a period of several days, resulted in a weakening of the mortar. Only the outer walls of the bridge are cemented together with mortar. This weakening, along with the tremendous pressure of the water and the buoyancy forces, resulted in destroying one span of the bridge.

An elementary estimate of the stresses existing in the bridge may be made by assuming the span to be a simply supported beam (which results in greater mid-span stresses than a clamped beam). The dead weight of the span, assumed to be 75 feet long, 17.75 feet wide, and 5 feet deep (average), was estimated to be $.9 \times 10^6$ pounds, or 12,300 pounds/feet. The additional pressure due to Concorde overflight will be 1.42 pound/feet.

Maximum compressive stress at mid-span is estimated to be $.7 \times 10^6$ psf due to the dead weight and 84.4 psf caused by the overpressure. Because of a lack of statistical data on the breaking stresses of stone arches, no probability calculation can be made. However, it is safe to conclude that the addition of 84.4 psf to the dead weight stress of 700,000 psf is not likely to cause failure of the bridge.

(2) Tollhouse Windows

The sound level at Broad Run Tollhouse due to Concorde Operations is estimated to be 88 dB(A). Taking into account the spectrum of noise and the natural frequency of vibration of the lites, the overpressure experienced by the lite will be .05 psf. For comparison, maximum sound levels of 78 dB(A) were measured at the site during DC-9 and Boeing 727 passbys.

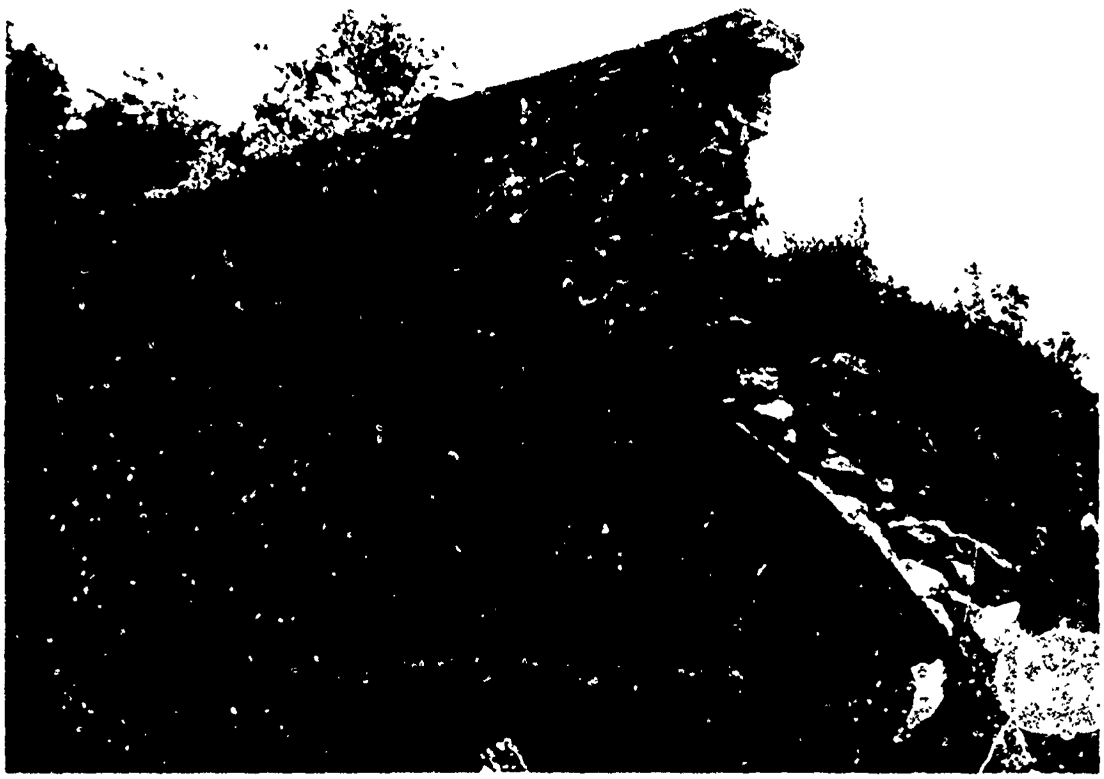
The lite size of the Tollhouse windows is 10 by 10 inches. The breaking strength distribution and stress factors will therefore be similar to those estimated for the Sully Plantation lites.

Using the procedure of Section II, the probability of breakage for healthy glass is calculated to be 5×10^{-22} per lite per overflight, or 1.55×10^{-16} per year for all 213 lites.

If we assume that one of the lites is cracked, its probability of failure will be 2.15×10^{-7} per year, or one failure per 4.6 million years.

FIGURE V-1
Tollhouse at Broad Run

FIGURE V-2
Broad Run Bridge After Being
Damaged by Hurricane Agnes in 1970



VI. MANASSAS NATIONAL BATTLEFIELD PARK

1. STONE HOUSE

(1) History and Description of Structure

The old Stone House is one of the most notable landmarks of the Manassas National Battlefield Park. It is located at the intersection of the Warrenton Turnpike and Sudley Road (now Routes 29-211 and 234).

The Stone House was constructed in the 1820's probably as a tavern to serve the Warrenton Turnpike. With the advent of railroads and a canal system, the Stone House's function as a tavern was short-lived. Figure VI-1 shows the Stone House in its restored condition.

As turnpike traffic died, the history of the Stone House was rather obscure until the Civil War. On July 21, 1861, the fighting at First Manassas began just 1/3 mile north of the house. Nine hundred Confederates under General Evans met two brigades of Union soldiers. After fierce fighting, the Confederates fell back; some took shelter behind the solid walls of the Stone House, while others fired at the approaching enemy from the second story.

A Union surgical team used the house later as a field hospital. The walls stopped the heaviest shells, thus protecting the wounded.

In August 1962, there was renewed fighting in the area near the Stone House. Again, the Stone House served as a hospital. After that time the Stone House was a private residence. The George Ayers family owned the house from 1902-49. In 1949, the house was purchased by the National Park Service of the Department of the Interior.

Nothing definite is known about the original construction of the Stone House except that it probably was used as a tavern. It stands on the old "Pittsylvania" estate belonging to Landon Carter, son of "King" Carter who patented the Bull Run tracts of land in 1724. It is believed that the house was left in an unfinished state of completion after its construction, undergoing changes to the interior.

The Stone House has two stories, with a full attic and basement and chimneys centrally located at each end. The house has a hall placed off-center with a large parlor to the west and two small rooms to the east. The same arrangement is found on the second floor. Building materials used in the construction of the house include Seneca sandstone quarried from a nearby hill, mortar, wood plaster, and flagstone. Yellow clay was probably used as mortar which has contributed to the weakness of the walls throughout the building. The interior of the house was plastered and whitewashed.

In 1961, the Stone House was restored by the National Park Service to the 1860 period when it served as a field hospital. Today the Stone House is open to the public and furnished as if it were an active Civil War hospital.

(2) Probability of Breakage

In the case of the Stone House the windows will be the most susceptible to breakage from Concorde noise.

The sound level from Concorde's overflights has been estimated to be 70 dB(A) at the Stone House, which would result in an overpressure of .00625 psf at the windows. In comparison, the automobile traffic on the Warrenton Turnpike measured 65 to 70 dB(A). The road is also used by trucks carrying gravel from nearby quarries, which could result in levels as high as 80 dB(A) at the Stone House.

Most lites in the Stone House measure 10 by 12 inches, with a thickness of 1/16 to 3/32 inch. None of the lites are original; however, some may date back to the 1860's period after the Manassas battles. The closeness of the lite size to the lites at Sully Plantation allows us to use the breakage strength distribution and noise stress factor for calculating the breakage probabilities at Stone House.

For Concorde noise levels of 70 dB(A), the effective safety factor for glass lites is 12.523, and the probability of breakage is 2.8×10^{-36} per flight.

Since there are 250 lites at the Stone House and four Concorde flights per day from Dulles International Airport, this probability translates to one lite breaking every 2.4×10^{14} years.

The chimneys at the Stone House are in sound condition and have short unsupported lengths. The probability of chimney failure will be smaller than that of glass.

2. STONE BRIDGE

(1) History and Description of Structure

The Stone Bridge is located in the Manassas National Battlefield Park. It spans Bull Run over the Warrenton Turnpike and was built in 1814. Figure VI-2 shows the Stone Bridge in its restored condition. The bridge became famous during the Civil War Battle, First Manassas. It was there that the first battle shots were fired on the morning of July 21, 1861. During that evening, a portion of the Union Army retreated across the bridge. During the battle of Second Manassas, the Stone Bridge served not only as the main avenue of the Federal advance but, more significantly, as the key escape route in the retreat. Stone Bridge was partially destroyed by Federal troops during their retreat at the battle of Second Manassas the night of August 30, 1862.

Major Franz Blessing, commanding 74th Pennsylvania, co-operated with Kane's Bucktails in the destruction of the bridge:

> "We then marched to the Bull Run, and were ordered to remain there until all the wagons and ambulances had passed over the bridge. After this was done, Captain A. Mitzel, with two companies of the regiment, was ordered to destroy the bridge, which order was filled with many difficulties." (Shurz's Report p. 311.)

In a photograph of the bridge (Figure VI-3) taken shortly after its destruction, structural detail serves to establish that much of the present bridge is original following the destruction of the two center arches. There are buttress walls on the west bank, flat stone capping and drain holes on the north face of the wall located on the east bank. The bridge is reportedly to have been down three times prior to the Civil War.

In 1961, Stone Bridge was restored by the National Park Service. The roadbed was removed, and all the rubble fill was cleared from the center of the bridge. The east wall was rebuilt and mortar repaired inside and out.

Hurricane Agnes damaged the roadbed and flat stone capping of the bridge in 1970. These were subsequently repaired.

Stone Bridge serviced the Warrenton turnpike until 1926. It is now closed off and is included as part of the historic sites of Manassas National Battlefield Park.

(2) Probability of Breakage

The sound level at the Stone Bridge due to Concorde is estimated to be 74 dB(A), or .0021 psf (A weighted). Based on the spectrum of Concorde noise, this would cause an overpressure of .0157 psf at the bridge structure.

The failure mechanism of a stone bridge of this type is extremely complex. The stresses in the bridge under a continuous loading may be estimated by assuming the span to be a beam with clamped ends, carrying a load varying from a

minimum in the center of the span to a maximum at the ends due to its dead weight, with a uniformly distributed load due to the Concorde flyover superimposed on it. Assuming a density of 139 pounds/feet^3 for the stone and bridge dimensions, illustrated in Figure VI-4, a maximum stress of $.3876 \times 10^6 + 400\ p_b$ pounds/square foot is obtained at the center of each span.

The compressive stress, which will be maximum at the top, far exceeds the additional stress induced by the sound pressure due to Concorde.

The historical data available for this bridge indicates that the Union Army had considerable difficulty in destroying the bridge after their retreat. Hence, the probability of damage to the bridge due to aircraft noise is extremely small.

Noise at the bridge site due to heavy truck traffic on the new bridge, which is parallel to old Stone Bridge, was measured to be 80 to 84 dBA.

3. DOGAN HOUSE

(1) History and Description of Structure

The Dogan House was one among several buildings that comprised the small town of Groveton, Virginia, during the mid-19th century. The house was probably constructed between 1817-19. At that time the house existed as a single

room, one-story structure which probably served as quarters for the farm overseer. See Figure VI-5.

The frame building, which composes the north half of the present Dogan House, was moved from its "Peach Grove" site in 1860 and attached to the log cabin. This provided a temporary residence for Mrs. Lucinda Dogan and her children.

The Dogan House was restored by the National Park Service in 1961 and is one of the historic sites at Manassas National Battlefield Park. Much of the early construction detail is unknown but the house was restored based on archeological information.

During restoration, a minor exploratory search of the grounds immediately surrounding the building uncovered an old stone walk, a large number of rifle and pistol balls, Minie balls, cannister shot, cannon shell fragments, one bayonet, and numerous hardware and household articles.

The basic design of the Dogan House was restored to its present appearance in 1860, immediately before the Civil War. The house consists of a story-and-a-half log cabin attached to the north by a frame addition, one room with attic building. Near the center of the house is a stone masonry chimney with a fireplace in each of the two first-floor rooms.

(2) Probability of Breakage

The sound level at Dogan House due to Concorde operations is estimated to be 67 dB(A), resulting in window overpressures of 4.42×10^{-3} psf for 6 seconds per flight.

The lite size at Dogan House is 8 by 10 by 1/16 inches; hence, glass strength distribution will be similar to that for Sully Plantation and Stone House.

The effective factor of safety for glass breakage is 13 for healthy glass and 9.74 for cracked glass. There are only about 50 lites in Dogan House, and the probability of glass breakage is 3.6×10^{-34} per year for healthy glass, and 7.2×10^{-18} per year for cracked glass.

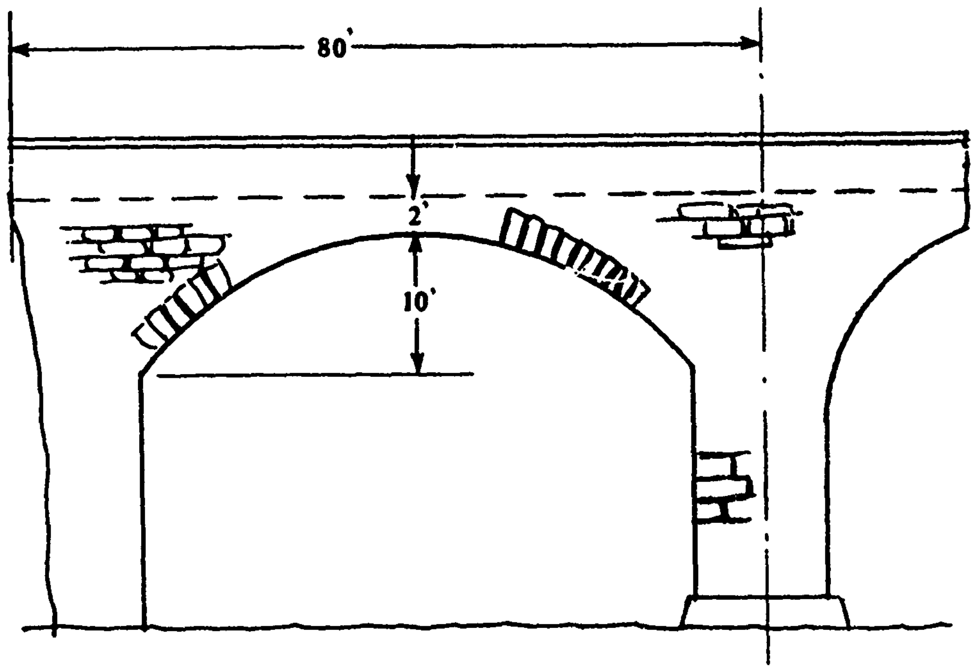
The probability for chimney breakage will be even smaller.

FIGURE VI-1
Stone House in Restored Condition

FIGURE VI-2
Stone Bridge in Restored Condition

FIGURE VI-3
Stone Bridge Partially Destroyed
During Civil War

FIGURE VI-4
Stone Bridge



Bridge Width = 25 feet

FIGURE VI-5
Dogan House

VII. SAINT GEORGE'S CHURCH

1. HISTORY AND DESCRIPTION OF STRUCTURE

Saint George's Church is located on the corners of Front Street and Washington Street in Hempstead, New York on Long Island. Several structures have been built on this parcel of land—serving as the meeting house for the Church of England. The present building was built in 1822 and represents one of the purest examples of Georgian Architecture existing today. See Figure VII-1. The great columns within are the original ones—cut on the Hempstead Plains as shown in Figure VII-2.

Saint George's Church is listed on the National Register for Historic Places not only for its architecture but for its long history of the site since 1643 when Reverend Robert Fordham and John Carmen purchased the land from Chief Tackapousha for 1/7 cent per acre.

The first meeting house was built in 1648 by the town of Hempstead. The second meeting house was erected in 1673 at public cost for religious and secular purposes. The religious services were of no particular faith but just the "Word of God."

In 1734, by a vote at a Town Meeting a 1/2 acre was given on which to build a Church of England and use as a burial ground. The building was built by the pioneers. The frame was large hewn oak timber. The dimensions were approximately 40 feet long and 26 feet wide.

King George II of England granted a Royal Charter to the Parish in Hempstead, Queens County in 1735. This Charter is still in possession of the church today. During the Revolutionary War, Saint George's Church was used as a military store house, the communion table was used as an eating table in spite of the protests, and the British used the gravestones from the grave yard as hearth stones.

In 1822, the present church was erected at a cost of approximately $5000. The church was 64 feet long and 42 feet wide with a vestry room in the rear and a steeple with cupola and bell in the front resting partly on the body of the building. There was a gallery on both sides of the church.

In 1856, the recess chancel was built where the altar is now situated. This was 25 feet wide and 17 feet deep. A robing room adjoins. The total cost of this addition was $1300.

In 1862, due to leaks in the roof, a portion of the ceiling had fallen. At this time a new ceiling was put up and the roof covered with slate.

Presently, the church still has the original plaster on the walls and nine original Tiffany stained glass windows one of which is shown in Figure VII-3. Over the altar is a round window containing the likeness of a gilt dove bearing a gilt olive branch in his beak. (See Figure VII-4.)

The ceiling of the church has recently been replastered over the old plaster.

Atop the steeple is a weather vane where one can still see the 16 bullet holes put there by Revolutionary soldiers. The clock on the steeple still operates and is older than "Big Ben" in London.

Saint George's Church is still active today as an Episcopal Church.

2. PROBABILITY OF BREAKAGE

The long distance of the Saint George's Church from JFK Airport results in maximum sound levels due to Concorde overflights of only 67 dB(A). To the human ear, this level is comparable to the sound of a heavy truck at a distance of 400 feet. However, the spectrum or character of noise from the Concorde is different and we shall examine its effects.

Parts of the church most likely to be damaged by vibrations due to airborne sound are its stained glass windows and the ceiling plaster. Of the 23 stained glass windows in the church, nine are considered to be very valuable and irreplaceable. They are made of Tiffany glass, dating to the mid-19th Century. All nine Tiffany windows are located on the main level of the church hall. The ceiling was recently replastered over the original plaster, the new plaster held in place by metal lathing. Several long cracks are already visible in the new plaster.

(1) Probability of Breakage of Stained Glass Windows

Each stained glass window is made up of a number of small pieces of glass of different colors assembled together by lead cames to form a composite religious figure (see

Figure VII-3). Each piece of glass, due to its small size, will have a greater breaking strength than the composite. Therefore, to analyze the strength on the basis of weakest member, each stained glass section is metal sash measuring 15-1/2 inches x 48 inches is considered as one lite. The thickness of this lite varies from 1/8 inch to 5/16 inch. Assuming that the breaking strength is determined by the weakest and hence the thinnest section of the lite, we calculate the breaking pressure to be 204 psf. The resonant frequency of the stained glass section is 56.6 Hz.

This is above the resonant frequency of the plate glass at the Anchorage hotel instrumented by Rickley, et al.[3]; hence, the airborne sound pressure experienced by the glass will be increased by a factor not exceeding 4.73 over the A-weighted sound level:

$$p_n = 4.42 \times 10^{-3} \text{ psf.}$$

Using the procedure from Chapter II we obtain

$$P = 1.0665 \times 10^{-29}$$

as the probability of breaking a lite on any given overflight.

Taking eight overflights per day and a total of 23 windows, we get

$$\begin{aligned} P_{breakage} &= 8\,(365)\,(23)\,(1.0665 \times 10^{-25}) \\ &= 7.1626 \times 10^{-25} \text{ per year} \end{aligned}$$

or one failure per 1.396×10^{24} years.

(2) Probability of Damage to Plaster Ceiling

In view of the fact that the plaster is located in the interior of the building where outdoor sound levels will be attenuated at least 10 dB even when the windows are open, the probability of damage to the ceiling will be even lower than that of damage to the stained glass windows calculated in the previous section. In tests conducted to predict the probability of damage to structural plaster from sonic booms, it was found that the mean breaking pressure of plaster is about two to seven times that of glass.

FIGURE VII-1
Saint George's Church

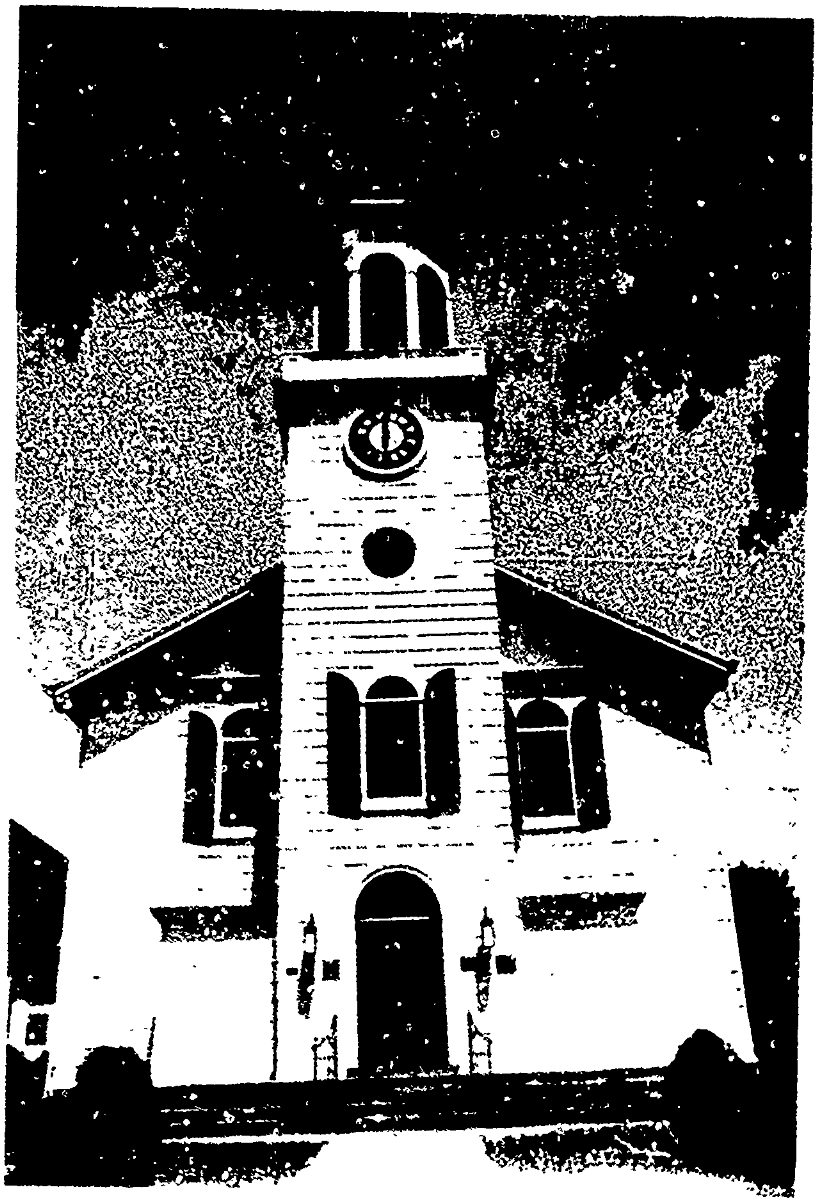
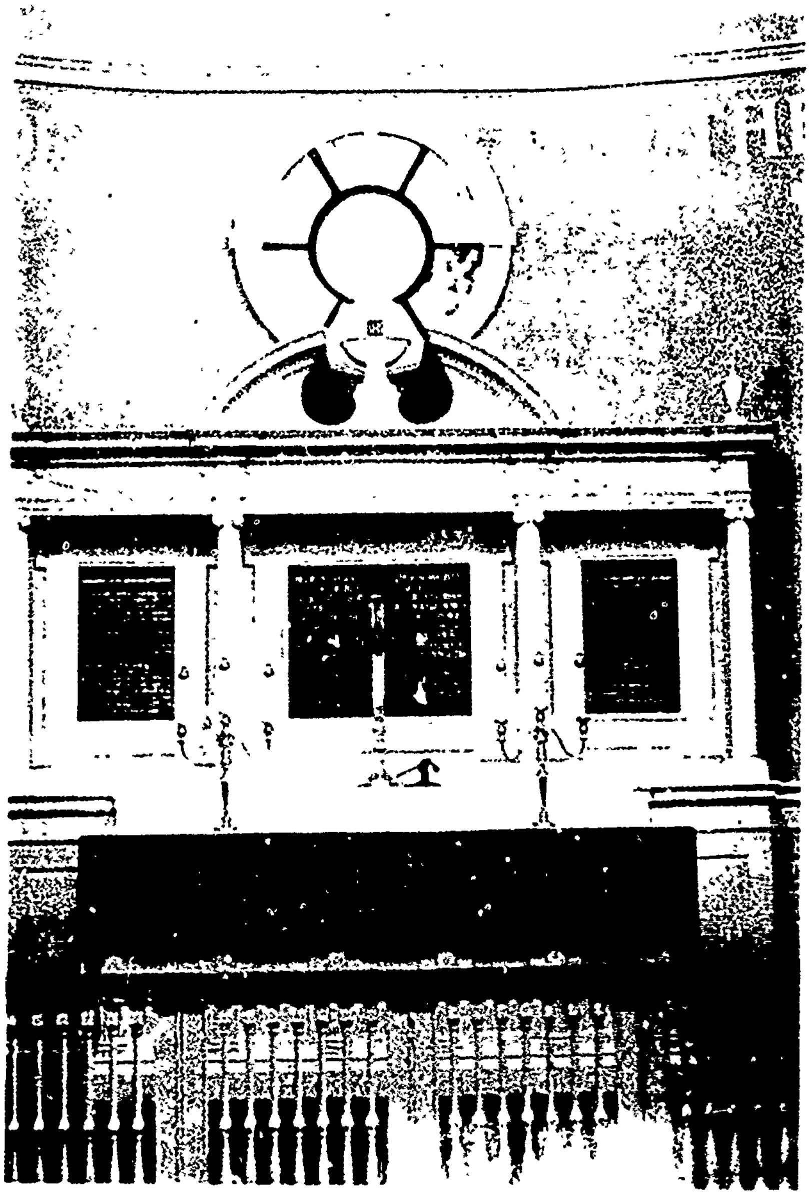


FIGURE VII-2
Interior of Saint George's Church

FIGURE VII-3
Tiffany Stained Glass Window
at Saint George's Church

FIGURE VII-4
Round Window in Recess Chancel
of Saint George's Church



VIII. CONCLUSIONS

Breakage probabilities at the five historic sites have been calculated using the response probability function technique. The results are summarized in Table VIII-1. In general the breakage probabilities were calculated to be less than .001 for a year of Concorde operations; the only exception was the case of already cracked lites at Sully Plantation. These each had a yearly breakage probability of 20%. If these lites are replaced by healthy lites, then the breakage probabilities at the sites will be negligible for all structural elements.

In reviewing the results in Table VIII-1 it is readily apparent that the breakage probabilities at Sully Plantation are orders of magnitude higher than at any other site investigated. This is because of the fact that Sully is extremely close to the flight path, being located on land which is part of Dulles Airport itself. Because of this proximity there is some risk of further cracking of cracked glass. Four such lites were observed during a recent visit there. The other sites have all their breakage probabilities, even those for cracked glass, considerably below the failure rates that would be expected just from exposure to the weather

In conclusion, the risk of damage to healthy glass, plaster, chimneys, and bridges at the sites is negligible from projected Concorde overflights. However, the cracked lites at Sully Plantation are only expected to survive an average of five years of Concorde noise vibration exposure. After the replacement of these lites there should be no practical risk of aircraft noise-induced vibration damage to any of the historical structures investigated.

Table VIII-1
Summary of Breakage Probabilities

Historic Structure and Structural Element	Probability of Failure Due to One Year of Operations	Number of Years Between Failures
SULLY PLANTATION		
Windows—324 Lites	8.2×10^{-7}	1.22×10^{6}
Each cracked lite	.19	5.27
Chimneys	2.3×10^{-6}	4.4×10^{5}
Garret Room Plaster	2.5×10^{-4}	4.0×10^{3}
DRANESVILLE TAVERN		
Windows—210 Lites	1.3×10^{-32}	7.7×10^{31}
Each cracked lite	7.3×10^{-19}	1.4×10^{18}
Chimney—Kitchen	1.7×10^{-12}	5.76×10^{11}
BROAD RUN TOLLHOUSE		
Windows—213 Lites	1.5×10^{-16}	6.45×10^{15}
Each cracked lite	2.15×10^{-7}	4.6×10^{6}
MANASSAS BATTLEFIELD PARK		
Stone House—250 Lites	1.025×10^{-30}	9.75×10^{29}
Each cracked lite	1.66×10^{-17}	6.02×10^{16}
Dogan House—49 Lites	3.63×10^{-34}	2.75×10^{33}
Each cracked lite	1.5×10^{-19}	6.76×10^{18}
ST. GEORGE'S CHURCH		
Stained Glass Windows	7.16×10^{-25}	1.4×10^{24}

LIST OF REFERENCES

1. Federal Aviation Administration, "Concorde Supersonic Transport Aircraft, Draft Environmental Impact Statement," March 1975.

2. Wiggins, John H., "Sound and Vibration Measurements for Concorde Supersonic Transport and Subsonic Jet Aircraft," Department of Transportation, Office of Noise Abatement, Report No. DOT-T5T-75-21, July 31, 1974.

3. Rickley, E. J., Quinn, R. W., and Sussan, N. R., "Noise Emissions and Building Structural Vibration Levels From the Supersonic Concorde and Subsonic Turbojet Aircraft," Department of Transportation, Office of Noise Abatement, Report No. DOT-TSC-OST-74-35, March 1975.

4. Wesler, J. E., "Comparative Noise and Structural Vibration Levels From Concorde and Subsonic Aircraft," presented at NOISEXPO 75, Atlanta, Georgia, May 2, 1975.

5. Hershey, Robert L., Higgins, Thomas H., and Magrab, Edward B., "Application of the Response Probability Density Function Technique to Predicting the Probability of Sonic Boom Glass Breakage," Journal of the Acoustical Society of America, Volume 55, No. 5, May 1974.

6. Hershey, Robert L. and Higgins, Thomas H., "Statistical Prediction Model for Glass Breakage From Nominal Sonic Boom Loads," Prepared for Federal Aviation Administration. Report No. FAA-RD-72-43, January 1973 (AD-763 594).

7. Hershey, Robert L., "Statistical Model of the Rupture of Brittle Rectangular Plates Under Loading by Transient Overpressures," Ph.D. Dissertation, Catholic University of America (1973).

8. Hershey, Robert L. and Turner, Louie, "Aircraft Taxiing Noise Measurements," Appendix C—Prediction of the Probability of Window Breakage From Jet Noise, Prepared for Federal Aviation Administration. Report No. FAA-RD-74-114, August 1974 (AD 787-235).

9. Hershey, Robert L. and Higgins, Thomas H., "Design of Windows for Dynamic Loading," Sound and Vibration, March 1975.

10. Kryter, Karl, et al., "Sonic Boom Experiments at Edwards Air Force Base," Stanford Research Institute, July 28, 1967.

11. Shand, E. B., Glass Engineering Handbook, McGraw-Hill, New York, 1958.

12. White, R., "Effects of Repetitive Sonic Booms on Glass Breakage," Wyle Laboratories, FAA Report No. FAA-RD-72-43, April 1972.

13. Fishburn, Cyrus C., "Effect of Mortar Properties on Strength of Masonry," Monograph 36, National Bureau of Standards (1961).

14. Copeland, R. E., and Saxer, E. L., "Tests of Structural Bond of Masonry Mortars to Concrete Block," Proceedings, American Concrete Institute, Vol. 61, No. 11, Nov., 1964.

15. Leigh, Barry R., "Lifetime Concept of Plaster Panels Subjected to Sonic Boom," UTIAS Technical Note No. 191, University of Toronto, July 1974.

16. Diehl, John R., "Manual of Lathing and Plastering," National Bureau for Lathing and Plastering, 1965.